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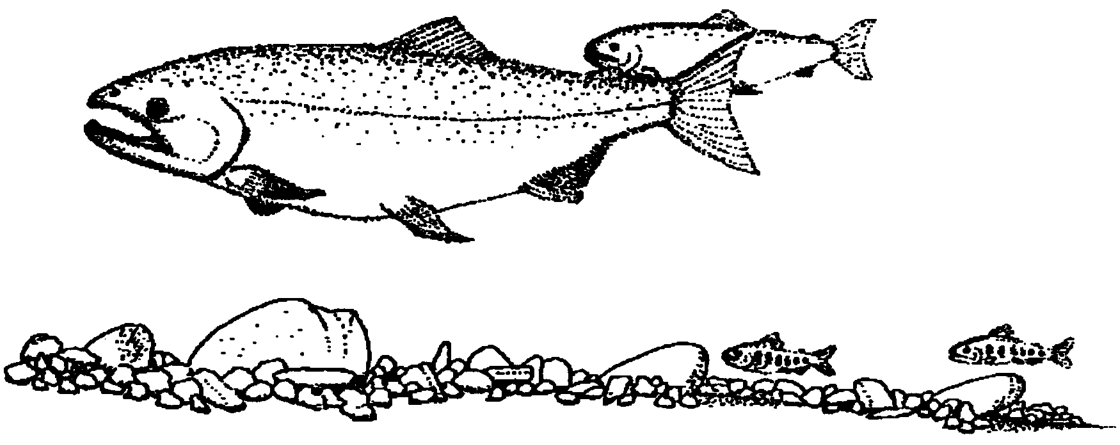

WESTERN WASHINGTON FISHERY RESOURCE OFFICE

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STATUS OF KOKANEE SALMON
(*Oncorhynchus nerka*)
IN THE
LAKE SUTHERLAND BASIN
AND
PROSPECTS FOR
SOCKEYE SALMON RESTORATION

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ABSTRACT

Adult kokanee distribution and abundance in Lake Sutherland and its tributaries, Clallam County, Washington were examined by foot, canoe, or towed divers with simultaneous SONAR survey in the lake. Virtually all kokanee spawned in the lake. Tributary streams had little spawning habitat and received few, if any spawners. Most lake spawning occurred between the depths of 0.3 to 10.7 m (1-35 ft). Spawning was concentrated parallel to 0.8 km (0.5 mi) of shoreline near Falls Creek at the lake's southwest corner. A much smaller concentration of spawners centered around the lake outlet (Indian Creek). Most carcasses near Indian Creek were on the lake shore, but some were in the creek between the lake outlet and the fish barrier screen 0.16 km (0.1 mi) downstream from the lake. Spawn timing peaked in mid-November in the Falls Creek area, and probably in the Indian Creek area. Adult kokanee may also concentrate at three other subsurface locations in the lake; however, SCUBA survey was insufficient to detect redds in these areas. A total carcass count along shore indicated a minimum spawning escapement of 3,200 adult kokanee. Potential sockeye run size was estimated at 4,000 to 6,000 adult fish, based on the sum of historic high annual kokanee catch plus the 1993 season's kokanee escapement. Horizontal sinking gillnets set on the principal spawning grounds provided abundant live, mature adults for genetic stock identification. The magnitude of escapement suggested a good supply of smolts for captive rearing and development of a sockeye run when migratory blocks to saltwater are removed.

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GLOSSARY

FERC -- Federal Energy Regulatory Commission

Green fish -- A mature adult having eggs or milt which does not flow readily when the fish is handled.

Mass spawning area -- lake or stream bottom disturbed by spawning in a way that obliterates individual nest boundaries.

Mature fish -- An adult that is either green or ripe.

Redd -- For this report, any discreet area of lake bottom considered disturbed by spawning kokanee. This definition includes both individual spawning nests and areas of mass spawning activity.

Ripe fish -- An adult having eggs or milt flowing readily when the fish is handled.

Shore miles -- Miles of lake shoreline counted clockwise beginning at Washington Department of Wildlife public boat launch. Shore miles appear in map in Figure 2.

Spent fish -- An adult which has no remaining eggs or milt.

USDI -- United States Department of the Interior

USFWS -- United States Fish and Wildlife Service

USGS -- United States Geological Survey

WDFW -- Washington Department of Fish and Wildlife

WWFRO -- Western Washington Fishery Resource Office of United States Fish and Wildlife Service

INTRODUCTION

The Elwha River in Clallam County, Washington has two dams which completely block upstream fish migration (Figure 1) to over 112 km (70 mi) of usable mainstem and tributary habitat (USDI et al. 1994). The Elwha River Ecosystem and Fisheries Restoration Act (PL 102-495) of 1992 established the goal of full restoration of the Elwha River's ecosystem and native anadromous fisheries (Section 3(d)). Analysis by USDI et al. (1994) determined that removing the dams was not only feasible but was the only way to achieve the Restoration Act's goal.

If dam removal occurs, federal, state, and tribal fishery agencies plan to accelerate the restoration process by releasing hatchery-reared juvenile salmonids into the river upstream of the dam sites for 8 to 10 yr after safe fish passage is assured (USDI et al. 1994). The agencies are now preparing refinements (WWFRO 1993a, 1993b) to the fishery restoration plan (USDI et al. 1994) which will determine salmonid stock availability from the Elwha basin and nearby areas for rebuilding the upper basin's anadromous fish runs. The plan will also provide details to support the required Environmental Impact Statement on dam removal.

FISHERY HISTORY

Historical accounts identified kokanee in Lake Sutherland prior to construction of the Elwha Dam (USDI et al. 1994), and verbal records indicate a historical sockeye run (FERC 1993, Adamire and Fish 1992). This contradicts an earlier assessment (Hosey and Associates 1988) that Lake Sutherland kokanee were derived exclusively from WDFW releases of hatchery fish.

Since 1911 the Elwha Dam has completely blocked upstream fish passage (USDI et al. 1994). However, in 1917 sockeye were among the species returning to the Elwha Hatchery (Adamire and Fish 1992). These authors stated that between 1918 and 1922 very few salmon ascended as far upriver as the Elwha Dam, with the result that hatchery operations were discontinued in 1922. The FERC report (1993) states that a few sockeye are seen in the lower Elwha each year, citing Ward and Hoines (1987). However, the FERC document (p. 80) indicated sockeye entered the Lower Elwha Clallam tribal catch in only two years between 1978 and 1987 -- 7 fish in 1981 and 4 fish in 1985. The FERC (1993) authors believe these are strays, possibly from the Ozette, Quinault, Baker, Cedar, or Fraser Rivers. Hatchery kokanee were released into Lake Sutherland from 1933 through 1964 from the Lake Crescent, Aberdeen, Quilcene, and South Tacoma Hatcheries (Appendix A) but the geographical origin of these releases was not recorded. Sources probably included British Columbia, Montana, Idaho, and Lake Whatcom, the latter being the main source in 1950's and 1960's (Bill Freymond, WDFW, pers. comm.).

Creel census was conducted on Lake Sutherland from 1960 through 1965 and from 1978 through 1989 (Table 1). Catch per angler varied greatly from one year to another, but was particularly high in 1961, 1965, and 1986.

Spent kokanee have been observed on shore in mid-November (Freymond, pers. comm.). A lake shore resident noted relatively low numbers of spent carcasses on the shore in November of 1990 and 1991, but clearly higher numbers in that month in 1992 and 1993 (Al Owen, pers. comm.).

RESTORATION PLAN

The restoration plan includes sockeye salmon (*Oncorhynchus nerka*), which is believed to have historically spawned and reared in Lake Sutherland (FERC 1993). Landlocked *O. nerka*, or kokanee, reside in Lake Sutherland, and may be composed of remnant Elwha sockeye. The USDI et al. (1994) propose two concurrent restoration processes: enhancing the anadromous component of Lake Sutherland kokanee (assuming it retained a significant genetic element of the original Elwha sockeye) or seeking a suitable outside stock. Kokanee, even though landlocked for many generations, may produce anadromous offspring (USDI et al. 1994) which through captive rearing might be used to restore depleted sockeye stocks, as is proposed for recovery of the endangered Snake River sockeye. Smolts would be trapped at the outlet weir, captive reared to maturity, and their offspring returned to Lake Sutherland over one or more cycles prior to removal of the Elwha Dam. Concurrently, other potential sockeye donor stocks would be screened. If use of Lake Sutherland kokanee proved not feasible, sockeye fry from a suitable donor stock would be introduced into Lake Sutherland beginning one year prior to Elwha Dam removal.

Based on these considerations, the USFWS (WWFRO 1993a) identified three research goals for 1994, which were endorsed by the cooperating agencies in Elwha River fishery restoration:

I. "Evaluate spawner capacity of Lake Sutherland and tributaries (fall spawner surveys via foot and boat/towed diver);

II. "Evaluate Lake Sutherland rearing capacity (seasonal limnological surveys; profile existing fish community via gillnetting and electrophoretic analyses of kokanee stock, including scale and otolith analyses); and

III. "Assess anadromous potential of Lake Sutherland kokanee by fyke netting kokanee "smolts" during spring at lake outlet for ATPase/saltwater challenge."

OBJECTIVES

This report addresses all aspects of the above goals that could be answered by field investigation of the 1993 spawning run of Lake Sutherland kokanee. Our objectives were to:

(1) Evaluate spawner abundance and distribution within the Lake Sutherland basin, and

(2) Profile the fish community.

STUDY AREA

Lake Sutherland (Figures 1,2) is located west of Port Angeles along Highway 101. The lake has the following characteristics (Bortleson et al. 1976):

Altitude:	160 m (525 ft)
Surface area:	146 ha (361 acres)
Drainage area:	21 sq km (8 sq mi)
Shoreline length:	7.8 km (4.9 mi)
Mean depth:	17.4 m (57 ft)
Maximum depth:	26.2 m (86 ft)
Principal inlet:	Falls Creek
Outlet:	Indian Creek

At the time of our survey a fish barrier screen on Indian Creek 0.16 km (0.1 mi) below the lake completely blocked fish migration to and from the lake. Since 1911 the Elwha Dam has blocked fish passage upstream from Km 7.8 (Mile 4.9) (Figure 1). In 1974, there was little evidence of submersed or emersed aquatic plant growth (Bortleson et al. 1976). However, in 1993 submerged aquatic plants were abundant (Appendix D). Surface temperature was 11.5°C (53°F) on November 4, 1993.

METHODS

SPAWNER SURVEY

To describe kokanee spawning distribution and abundance, spawner surveys were completed on Lake Sutherland and its tributaries. Surveys in the lake included a preliminary SONAR and carcass survey, shoreline foot and canoe survey, and a simultaneous SCUBA and SONAR survey. Foot surveys were completed in the lake tributaries.

Preliminary SONAR and Carcass Survey

To locate adult kokanee concentrations and focus subsequent survey efforts, a nearshore SONAR survey was made from a boat on November 4, 1993. The boat was equipped with a Bottom Line[1] Model TBL-300 downward-looking echo sounder, with a beam width of 100° and a frequency of 200 Khz. The boat proceeded along the lake shore over depths of 9.1 to 18.3 m (30 to 60 ft). Observers noted traces that might represent adult kokanee, and recovered floating kokanee carcasses. Locations were recorded on a map (Figure 2).

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[1] Mention of trade names or commercial products here or elsewhere in this report does not constitute endorsement by the U.S. Fish and Wildlife Service.

Foot and Canoe Survey

Foot or canoe surveys were used to count live kokanee and redds along the shoreline of Lake Sutherland.

Lake Shore and Outlet Stream Survey

Observers walked the shoreline from the WDFW boat launch to Falls Creek on 8 November and from the boat launch to shore km 1.0 (mile 0.6) on 16 November. The remaining lake shore was surveyed in a canoe. A canoe was also used to survey Indian Creek downstream to the fish barrier screen. All beached carcasses were counted and the number of redds (defined in Glossary) was estimated to a depth of approximately 3.7 m (12 ft).

Lake Tributary Survey

Foot surveys were used to assess kokanee spawning in tributaries of Lake Sutherland. Observers walked the unnumbered tributary at the boat launch upstream to a cascade that was clearly impassable to anadromous fish at km 0.16 (0.1 mi) from the lake on 4 November. They also walked Falls Creek to an impassable falls 0.16 km (0.1 mi) from the lake. We repeated the survey at the unnumbered tributary near the boat launch and Falls Creek on 16 November and walked an unnumbered tributary at shore km 0.3 (mile 0.20) upstream to an impassable culvert less than 0.16 km (0.1 mi) from the lake. We also surveyed an unnumbered tributary at shore km 6.7 (mile 4.20) upstream to a point approximately 0.5 km (0.3 mi) from the lake. No other tributaries were surveyed because they were not deep or wide enough to allow adult kokanee ascent.

SCUBA and SONAR Survey

To describe spawning distribution and habitat at depths not visible from the surface, a boat towing two SCUBA divers was used on 8 and 9 November 1993. We set courses roughly parallel to the shore from:

> shore km 0.0 to 1.0 (shore mi 0.0 to 0.6),
> shore km 2.8 to 3.4 (shore mi 1.75 to 2.15), and
> shore km 6.7 to 7.7 (shore mi 4.2 to 4.8).

(Shore miles are defined in the Glossary). These surveys were guided by the preliminary SONAR observations. A 6.7 m (22-ft) Mid-Jet boat with a Kodiak 460 inboard engine and jet drive unit towed the divers behind 30.5-m (100-ft) polypropylene lines. The divers, equipped with planing boards, could sound as deep as 13.7 m (45 ft) and, under the best conditions, observe the bottom to a depth of 17.7m (58 ft). The divers' combined field of vision was approximately 4.6 m (15 ft) wide. The divers could not follow separate paths since their planing boards lacked effective rudders.

Bottom depth and fish presence under the boat were monitored throughout each dive with a Larrance Model X-16 computerized SONAR apparatus. This instrument scanned the bottom with a 20° beam at a frequency of 192 Khz, and plotted bottom depth and fish traces on graph paper. Depth varied greatly within each dive. The steeply sloping bottom (Figure 2), coupled with several hundred private recreational piers and floats, prevented the boat and divers from setting a course over a constant depth. Variability was compounded by the 30.5-m (100-ft) tow lines, which prevented the divers from precisely following the boat's course.

Divers looked for live adult kokanee, carcasses, and redds. They also noted substrate type using the following classification:

C = cobble
G = mixed gravel
L = logs
PG = pea gravel
S = silt
SG = gravel covered with silt
V = rooted aquatic vegetation
W = small woody debris
? = bottom not visible

The divers, equipped with Ocean Technology Systems hard-wired MK1-DC1 diver air radio, communicated all observations of fish, redds, and substrate to a person in the dive boat, who recorded an entry for each dive minute. Mean depth under the boat over each dive minute was estimated from the SONAR printouts. Large SONAR traces near the bottom were interpreted as adult kokanee. These were totalled per dive minute and assigned to the mean bottom depth during the same minute.

POPULATION PROFILE

Gillnetting

We captured adult kokanee primarily for genetic identification and life history analysis, and secondarily to document presence of other fish species. We set four variable-mesh horizontal sinking gillnets within the kokanee spawning grounds as indicated by the preliminary boat survey. Nets were set perpendicular to the shore at shore km 0.2, 0.56, 0.64, and 0.7 (shore mi 0.15, 0.35, 0.4, and 0.45) (Figure 2).

The end of the net closest to shore was set in approximately 4.6 m (15 ft) of water, while the depth at the end farthest from shore ranged from 8.5 to 15.5 m (28 to 51 ft). Each net was 30.5 m (100 ft) long, 1.8 m (6 ft) deep, and consisted of 5 panels of white polyfilament mesh. Stretched mesh size ranged from 1.9 to 8.9 cm (0.75 to 3.5 inches). The head rope was buoyant polypropylene line without floats, and the foot rope was made of woven lead-core rope. Each end of the foot rope was anchored with a 10-lb concrete weight. Each end of the head rope was marked at the surface with a 6-in gillnet float. Nets were set between 4:15 and 4:50 PM on 4 November 1993, and were retrieved between 8:15 and 11:15 AM the following day.

Upon retrieval we counted each fish netted and determined the species. Live fish were sexed, the spawning stage was noted, and the fish were released. Mortalities were brought ashore for sex determination, length measurement, and electrophoretic sampling. A total of 86 adult kokanee were frozen for later electrophoresis and otolith examination. Fifty fish were sampled from the nets at shore km 0.56 to 0.72 (shore mi 0.35 to 0.45), and 36 were sampled from the net at km 0.24 (mile 0.15). A total of 17 cutthroat trout were also frozen for possible scale analysis.

RESULTS

SPAWNER SURVEY

Preliminary SONAR and Carcass Survey

Preliminary SONAR survey and carcass recovery suggested two adult kokanee concentrations along the north shore, one between shore km 1.8 and 2.7 (shore mi 1.1 and 1.7), and another between km 3.8 and 4.5 (shore mi 2.4 and 2.8). This survey also revealed one kokanee concentration on the south shore near Falls Creek between shore km 0.5 and 0.8 (shore mi 0.3 and 0.5 (Figure 3).

Foot and Canoe Survey

Lake Shore and Outlet Stream Spawning

Post-spawning mortality greatly increased between November 9 and 16. Lake shore surveys revealed 635 kokanee carcasses between the WDFW boat launch and Falls Creek on November 9 (Appendix B), and 1,835 over the same area on November 16 (Appendix C).

Carcass and redd distribution on 16 November suggested two spawning concentrations. The larger carcass and shoreline redd concentration was between the WDFW boat launch and Falls Creek (Figure 4), while a smaller concentration centered around Indian Creek. However, more carcasses near Indian Creek were on the lake shore south of the creek than in the creek. Most shoreline spawning occurred between depths of 0.3 to 0.9 m (1-3 ft).

Tributary Spawning

The four tributary streams provided very little potential spawning area. Falls Creek and the two nearby tributaries at shore km 0.02 and 0.3 (mi 0.01 and 0.2) (Figure 2) were accessible only for about 0.16 km (0.1 mi), being blocked by falls, cascades, or culverts. The fourth, at shore km 6.7 (mi 4.2), appeared to entirely lack spawning gravel. No live or dead kokanee were found in any tributary. Redds may have occurred at as many as 8 points along Falls Creek, and at as many as 3 points along the unnumbered tributary at shore km 0.02 (mile 0.01).

SCUBA and SONAR Survey

Fish and Redd Distribution Along Lake Shore

SCUBA survey with simultaneous SONAR revealed traces suggesting kokanee between north shore km 2.9 and 3.4 (mi 1.8 and 2.1) on 8 November 1993 (Table 2). No live kokanee or redds were seen in this area, but a few carcasses were found at shore km 3.4 (mi 2.1).

On the south shore, SONAR indicated an adult fish concentration just east of Falls Creek, tapering off gradually towards Snug Harbor (Figure 5). SCUBA observations indicated live fish were evenly distributed between Falls Creek and the boat launch, with another separate concentration near Snug Harbor (Figure 6). However, divers found redds only between Falls Creek and the boat launch, with most occurring between shore km 0.3 and 0.6 (mi 0.2 and 0.4) (Table 3).

Depth Distribution of Fish and Redds

SONAR traces suggested that adult kokanee occurred near the lake bottom at depths ranging from 3.7 to 15.5 m (12 to 51 ft) during daylight hours, with a clear concentration around 9.1 m (30 ft) (Figure 7). However, SCUBA divers, during concurrent surveys, observed live adult kokanee more frequently between 6.4 to 7.6 m (21-25 ft) and 11.0 to 15.5 m (36-51 ft) (Figure 8). Redds occurred at depths down to 12.2 m (40 ft) (Figure 9), and were concentrated at depth ranges of 0.9 to 6.1 m (3-20 ft) and 11.0 to 12.2 m (36-40 ft).

Substrate Types

Figure 10 suggests several connections between kokanee use and habitat type. SONAR traces presumably representing adult kokanee occurred far more frequently when divers reported submerged logs. Traces occurred slightly more frequently than average when divers reported silt, pea gravel, or mixed gravel. Divers observed live adult kokanee over gravel bottom, and above the average frequency over cobbly bottom. Spawning was only observed in "mixed gravel", not pea gravel, in all SCUBA surveys (Appendix D).

POPULATION PROFILE

Gillnetting Results

Gillnets captured 915 adult kokanee (Table 4), of which 618 were released alive from the nets (Appendix E). The most productive site was off shore km 0.6 (mi 0.35) (Figure 2). Stretched mesh sizes of 5.1 to 6.35 cm (2 to 2.5 inches) were most efficient in capturing kokanee (Table 5).

Sex ratio was approximately 3.6 males/female, or 78% males (Table 5). The 3.2 cm (1.25-inch) mesh tended to catch a higher percentage of males than in the catch overall, and females made up a larger part of the catch in the meshes of 5.1 cm (2 inches) and larger.

About 80 percent of the adult kokanee captured on 5 November were mature (Figure 11) (see glossary for definitions). The remaining fish were mostly spent adults, with very few immature juveniles. About half the females from the net closest to Falls Creek had already spawned, but no female captured near the boat launch had spawned (Figure 11). The two sites between these extremes had an intermediate number of spent females.

A large majority of both sexes clustered around the length of 250 mm (Figure 12). Males averaged about 5 mm longer than females.

The gillnets captured 19 cutthroat trout (*O. clarki*) (Table 6) and one sculpin (*Cottus* sp.).

DISCUSSION

ADULT DISTRIBUTION

Tributary Spawning

Kokanee spawn predominantly in the lake. A maximum of 11 redds were counted in the tributaries. In contrast, a minimum of 170 were counted on the lake shore. This contradicts an earlier report (Hosey and Associates 1988) which concluded that most spawning occurred in the tributaries. These tributaries could not support much more spawning than our maximum redd estimate. The tributary near Snug Harbor had a sand bottom throughout the 0.5 km (0.3 mi) of available habitat, and could not support salmonid spawning. In the three other accessible tributaries, very little spawning gravel was present. The predominant habitat type was cascade and the dominant substrate was boulder and cobble. In contrast, stream-spawning kokanee have been reported to spawn in gravelly stream margins, in pools, and behind large boulders (McCart 1970). Such habitat types were rare in Lake Sutherland tributaries.

Lake Outlet Spawning

We observed a concentration of kokanee redds in Indian Creek between the lake and the fish screen. This contradicts the findings of Hosey and Associates (1988) who minimized the importance of the outlet. These authors observed a high gradient reach which they believed would prevent juveniles from migrating from spawning areas within Indian Creek to the lake. We did not observe a high-velocity reach which would prevent juveniles from migrating into the lake, although such a barrier may exist downstream from the screen. It is possible that the outlet channel has changed since their surveys. We did not survey Indian Creek downstream from the screen for potential spawning habitat, since it seems that Sutherland kokanee are adapted primarily for spawning within the lake.

Spawning Distribution along Shore

Each survey method gave a different picture of distribution of fish along the lake shore (Table 7). There may be as many as five spawning concentrations or only one, depending on which combination of survey methods one accepts as definitive. We consider shoreline counts of carcasses and redds the best index of distribution of shore spawning, based on the large numbers observed and the correspondence between carcass and redd distribution. We consider occurrence of redds in SCUBA survey the only definitive indicator of spawning distribution at depth. This choice implies two kokanee spawning concentrations, a larger one extending from Falls Creek to Snug Harbor, and a smaller one centered around Indian Creek.

A combination of factors may explain the discrepancies between the results of the various survey methods, including:

- Schools of adult kokanee may have moved between survey dates.

- Observers may have misinterpreted SONAR traces.

- During the preliminary survey, floating log booms kept the boat operator from approaching the shore around the lake outlet.

- The preliminary SONAR and carcass survey may have covered a greater depth range than the subsequent SCUBA surveys.

- Schools of adult kokanee may range far from spawning grounds, even during the spawning season.

- Carcass distribution along shore may not represent distribution of spawners observed in SCUBA survey if carcasses of deep-spawning fish do not float as readily as carcasses of shore spawners.

- The divers' limited field of vision may have caused them to miss fish or redds throughout any given dive minute, especially in areas of shore surveyed only once.

- The fishes' reactive distance was long enough that they moved away before the diver saw them.

- Strong westerly winds could have moved carcasses from distant parts of the lake to the local spawning concentration observed on the east end of the lake near Indian Creek.

Spawning Depth Distribution

Depth distribution of fish and redds varied according to the method of observation (Table 8). The shoreline and SCUBA surveys considered together indicated three principal depth ranges of redd occurrence: 0.3-0.9 m (1-3 ft), 3.7-6.1 m (12-20 ft), and 11.0-12.2 m (36-40 ft). Shoreline redds probably depended on wave action for aeration, while deeper redds must have depended on subsurface springs. Location of springs probably accounts for the irregular redd distribution over depth, since lake-spawning kokanee tend to spawn near groundwater upwelling (Burgner 1991). Unfortunately, it was impossible to assess the relative contribution of nearshore versus depth spawning to the total escapement. The presence of hundreds of docks around the lake prevented the towed divers from observing redds near the shore. Moreover, redds at depths below 3.7 m (12 ft) would not be visible from shore or canoe.

There was no evidence that redds occurred below 13.7 m (45 ft), the maximum depth the towed divers could reach. The observed maximum redd depth of 12.2 m (40 ft) was slightly deeper than usual for kokanee. Maximum spawning depth is usually 9.1 m (30 ft) (Crossman and Scott 1973). However, much greater depths have been observed in a few Idaho lakes (Dave Beauchamp, Utah State University, pers. comm.).

The SONAR and SCUBA observations of live fish differed in the pattern of daytime distribution over depth (Table 8). While SCUBA observations indicated the same bimodal distribution as the redds, concurrent SONAR surveys suggested one peak in abundance midway between the two depth ranges within which live fish and redds occurred most frequently. We consider the SONAR results more reliable, for Sutherland kokanee may school some distance from the spawning grounds. Tributary-spawning kokanee in inland lakes have been observed to form schools near the thermocline and up to a mile from the spawning streams, even during the spawning run (D. Beauchamp, pers. comm.). Another reason for preferring SONAR data is that a boat passing over a school of fish might be less likely to disrupt them than a pair of divers passing directly through the school.

Substrate Preference

Based on SCUBA observations, Lake Sutherland kokanee spawning below 3.7 m (12 ft) used a larger range of gravel sizes (Figure 10) than that locally associated with kokanee. In Lake Ozette, kokanee are expected to use mostly pea gravel (M. LaRiviere, pers. comm.). In contrast to deeper redds, those visible from the shore usually occurred in pea gravel. This range in substrate textures falls within the broad range (coarse sand to immovable rubble) used by anadromous sockeye (Burgner 1991).

Mass Spawning

Spawning nests observed by divers usually overlapped to the degree that individual redds could not be counted. This may indicate that the number of spawners exceeded the spawning grounds' capacity. Alternatively, mass spawning may be an adaptation to the large substrate size of potential spawning grounds at the depths observed by divers, in contrast to the finer texture of spawning grounds observed on the beaches. If this mass spawning is primarily adaptive, we can make no inference regarding the lake's spawner capacity.

SPAWN TIMING AND DISTRIBUTION

Spawning apparently peaked in mid-November. Shoreline carcasses increased threefold between the spawner surveys on 9 November and 16 November. Occurrence of spent fish in the gillnets also supports early to mid-November spawn timing. Sixteen percent of the fish gillnetted on 5 November were spent, and 47 percent of the females caught at the Falls Creek net site were spent (Figure 11). This timing approaches the late end of the range for sockeye spawning near this latitude. For instance, the various Fraser river sockeye runs spawn between early August and late November, depending on mean annual incubation temperature (Burgner 1991).

The Indian Creek and Falls Creek spawning concentrations could be reproductively isolated. The most heavily used shoreline spawning areas were separated by approximately 3.2 km (Figure 3). Spawning populations do not need large geographic separation for reproductive isolation. Sockeye and kokanee spawning grounds in Redfish Lake are separated by only 0.8 km (0.5 mi). However, some gene transfer is considered possible, despite this separation (Brannon et al. 1992). Our observations support the hypothesis of a single population in Lake Sutherland and adjacent streams. The following points support this hypothesis:

- There was scattered spawning activity along the south shore between the two concentrations (Figure 4).

- Less than half the carcasses concentrated around Indian Creek were in waters with noticeable surface flow; most of these carcasses were in lake waters just south of the creek (Appendix C).

- The Indian Creek area carcasses appeared to be in the same state of decomposition as the Falls Creek group on the same survey day, suggesting no difference in spawn timing.

- The minimal tributary stream habitat means that the lake tributaries could hardly support enough fish to sustain a population distinct from the lake spawners.

- The hypothetical existence of isolated spawning grounds along two north shore areas -- that is, shore miles 1.0 to 1.8 and 2.3 to 2.9 (Figure 3) -- remains to be confirmed.

MINIMUM POPULATION ESTIMATE

A minimum adult population size of 3,174 was estimated by adding the November 16 carcass count to the number previously removed by a lakeside resident or by our observers.

Carcasses removed by lakeside resident before surveys	300
Carcasses removed in SONAR survey, 4 November	60
Mortalities in gillnet, 5 November	297
Carcasses counted on 16 November	2,517
Total	3,174

If all kokanee produced anadromous offspring, this escapement can be expected to produce 6,363 smolts, calculated as follows:

Minimum escapement	3,174
Percent females (Table 5)	22.0
Estimated females	698
Fecundity (Carlander 1969)	450
Estimated eggs	314,226
Percent survival to fry (Hosey 1988)	8.1
Estimated fry	25,452
Percent survival to smolt (Hosey 1988)	25
Estimated smolts	6,363

POPULATION PROFILE

Species Composition

The scarcity of cutthroat in gillnets (Table 6) does not reflect their abundance relative to kokanee, for cutthroat are expected to be dispersed throughout the open waters of the lake. Moreover, creel census (Dan Collins, WDFW, pers. comm.) indicates cutthroat almost always outnumber kokanee in the Lake Sutherland sport catch. On the other hand, this could be due to high catchability of cutthroat relative to population size. The low number of sculpin may reflect the nets' inability to touch bottom at all points.

Kokanee Characteristics

The preponderance of males observed here (Table 5) is typical of kokanee. In kokanee populations studied by McCart (1970) and Rutherford et al. (1988), males were generally dominant in all life stages and brood years, and accounted for 53 to 90 percent of the population. Our 3.2 cm (1.25-inch) gillnet mesh tended to catch a higher percentage of males than larger meshes because males' teeth protruded more than those of females, and were more easily snagged. Females tended to become entangled around the head and were more vulnerable to larger mesh sizes. Sex ratio was not determined in carcass counts.

Early November gillnetting probably preceded peak spawning by no more than a week. The low number of immature kokanee captured is expected since nets were set near the spawning grounds, not in open lake waters where juveniles are expected to occur.

Adult fork lengths fell in the mid-range reported for kokanee spawners. Cowichan Lake (British Columbia) kokanee matured at lengths ranging from 153 to 172 mm (Rutherford et al. 1988), whereas some Washington populations have individuals as large as 380 mm (Wydoski and Whitney 1979). The single sharp peak in length distribution at Lake Sutherland implies very little mixing between year classes.

RESTORATION POTENTIAL

Restoring Anadromy

Foerster (1947) succeedced in producing sea-run sockeye in the first generation from kokanee parents. Kokanee eggs from the Kootenay area were transferred to Cultus Lake, reared to yearling size, fin-marked, and released at a point having access to saltwater. Several marked fish were recovered as five-year-old sea-run adults in the commercial sockeye fishery and at the lake. However, smolt-to-adult survival was low compared to locally-adapted Cultus Lake stock.

McCart (1970) theorized that genotypes likely to produce kokanee would be strongly selected for whenever changing conditions result in net loss of reproductive capacity, for example, difficulties in migration to and from the ocean. He speculated that in kokanee populations above impassable falls, smolts would be rarer as the populations aged.

Scott (1984) reported that sockeye salmon were introduced to the Waitaki River in New Zealand from British Columbia in 1902, predominantly from Shushwap Lake sockeye. They have developed into a permanently freshwater stock, coincidental with the establishment of hydropower dams that block migration from the ocean.

Williams (1987) described the restoration history of upper Adams River sockeye, which became extinct after a series of temporary blockages prevented the majority of spawners from reaching their natal stream. Attempts to rehabilitate the population took place from 1954 to 1985. Egg and fingerling transplants from 1949 to 1975 resulted in very few returns to the river; however, spawners increased sixfold from 1980 to 1984. This was attributed to several factors. First, although the original transplants did not produce significant numbers of returning spawners, they probably provided a seed population which genetically fit the Upper Adams watershed. Second, short term rearing was included in the 1980 brood program, thus giving the hatchery sockeye fry an advantage over natural fry.

Partial verification of Cowichan Lake kokanee's anadromous potential was given by Rutherford et al. (1988), who showed that age 1 and 2 Cowichan Lake kokanee had some ability to osmoregulate in salt water.

Kaeriyama et al. (1992) documented a sockeye run established in Lake Toro, Hokkaido, Japan, in which neither sockeye nor kokanee had previously occurred. This run originated from two releases of fingerlings in 1988 and 1989 from a kokanee stock from Lake Shikotsu. The authors believed Lake Shikotsu stock originated from transplants of Lake Urumobetsu sockeye stock between 1925 and 1940, which had remained landlocked since that period. They concluded that both anadromous and resident types of *O. nerka* can be produced from both sockeye and kokanee salmon.

Formerly anadromous *O. nerka* stocks may retain the genetic drive for anadromy, which can be reestablished in subsequent generations (Bevan et al. 1992 citing Brannon (1992) and Gall (1992)). For example, Alturas Lake in Idaho has resident kokanee believed to be descended from sockeye (Jeff Gislason, Bonneville Power Administration, pers. comm.). However, use of kokanee to rebuild a sockeye run, even if the kokanee were derived from the original sockeye population, may proceed slowly if only a small fraction of the fish have the genetic material needed to produce a successful anadromous run (Bevan et al. 1992).

Genetic adaptability to change between anadromous and resident life history within a given river system was indicated by recent DNA typing in British Columbia. In general, stronger similarity existed between kokanee and sockeye native to the same lake and river system, than between kokanee populations of different lakes (C. Foote, pers. comm.).

Potential Lake Sutherland Sockeye Run Size

Potential sockeye run size at Lake Sutherland may be as high as 23,436 adults (FERC 1993, p. 3-28). The Point-No-Point Treaty Council (P. Crain, pers. comm.) has provisionally estimated a more modest sockeye potential, ranging from 6,177 to 9,764 adults. This was based on sockeye smolts produced per surface acre at comparable lakes elsewhere in the Northwest. Hosey and Associates (1988) estimated the potential sockeye run size as 108 adults, based on extent of tributary spawning habitat. These authors concluded that there was little possibility that a self-sustaining run of sockeye could be established. The FERC staff (1993) considered sockeye restoration potential "poor" due to "limited available habitat and lack of an identified donor stock from another river system."(P. 5-5) This low estimate can no longer be accepted because tributary and outlet stream area clearly do not limit the spawning capacity of the lake system. Nor is it clear that spawning habitat limits population size more than rearing capacity.

The present work suggests a potential naturally-produced run size ranging from 4,000 to 6,000 fish, derived from the sum of the highest historical sport catch (Table 1) plus the 1993 season's escapement estimated earlier in this discussion. The high estimate is based on a year in which hatchery stock may have augmented the catch; the low estimate is based on a year not influenced by recent hatchery releases (Appendix A).

Catch			Escapement			Estimated
Estimate	Year		Estimate	Year		run size
2,391	(1965)	+	3,174	(1993)	=	5,565
1,182	(1986)	+	3,174	(1993)	=	4,356

These estimates depend on the following assumptions:

- Virtually all sport-caught kokanee are adults.
- The kokanee sport catch is directly proportional to the total annual run size.

- The 1993 season's escapement is near the historic maximum.

- The maximum estimated run size represents all factors limiting the lake's capacity to support kokanee or sockeye, from egg deposition to adulthood.

- Estimated maximum kokanee run size is roughly equal to potential sockeye run size.

This estimate is close to the low run size estimate of 6,177 proposed by the Point-No-Point Treaty Council (pers. comm.), based on the number of sockeye smolts produced by lakes of comparable surface area. However, our method may underestimate smolt capacity. Kokanee must rear in the lake until adulthood. Thus, their population size may be limited by food and habitat availability for older fish. In contrast, sockeye smolt migrate to sea, which has a much higher rearing potential. In this case, run size will be limited only by the rearing potential for younger fish.

USEFULNESS OF SURVEY METHODS

SONAR alone is not a reliable guide to kokanee spawning grounds, but is helpful in directing diving operations to the more likely spawning areas.

Spawner survey along the shore from a canoe can produce a total beached carcass count for the lake in one day. This count is suitable for determining spawn timing, shoreline spawning distribution, and annual escapement trends. However, it is not suitable for accurately estimating total escapement, because there is no way to assess the relative contribution of shoreline spawners versus depth spawners to the total escapement. Redd counts are not suitable for estimating shoreline escapement, because Lake Sutherland kokanee tend to spawn in groups that obliterate individual nest boundaries.

SCUBA survey is essential to determine occurrence of adult kokanee or redds at depths greater than 1.8 m (6 ft). However, towed divers could not estimate spawning ground area. That is, the dive boat could not position the divers accurately enough to systematically map the potential or actual spawning grounds. Nor could SCUBA survey provide accurate fish counts, because kokanee tended to rapidly swim away at the edge of the divers' field of vision.

SUMMARY OF FINDINGS

1. Lake Sutherland kokanee spawned primarily on the lake bottom, to a lesser degree in Indian Creek (the outlet stream), and almost not at all in Falls Creek (the largest tributary) or any other tributary. Kokanee preferred gravelly bottom spawning areas.

2. A large majority of lake-spawning kokanee spawned on the south shore between Falls Creek and eastward to at least the WDFW boat launch, but possibly as far as Snug Harbor. A smaller concentration of spawning centered around the outlet stream (Indian Creek) and on the adjacent lake shore. SONAR survey suggested two other adult concentrations, both on the north shore, but SCUBA and canoe survey in parts of these areas failed to verify presence of live fish or redds.

3. Lake Sutherland kokanee spawned between 0.3-12.2 m (1-40 ft) below the lake surface, with most redds occurring between 0.3-0.9 m (1-3 ft), 3.7-6.1 m (12-20 ft), and 11.0-12.2 m (36-40 ft). However, it was impossible to estimate the relative contribution of nearshore versus depth spawning to the total escapement.

4. Spawning began before the first week in November and peaked by mid-November or shortly thereafter.

5. Minimum spawning escapement was estimated at 3,174 adults based primarily on a November 16 carcass count along the entire lake shore.

CONCLUSIONS REGARDING SOCKEYE RESTORATION POTENTIAL

1. The 1993 season's kokanee escapement and extent of potential spawning area within the lake suggest that the lake can potentially support a viable population of naturally-reproducing sockeye.

2. A determination of Lake Sutherland kokanee's genetic similarity to western Washington sockeye populations would help assess the likelihood of creating a sockeye run from local kokanee broodstock.

CONCLUSIONS FOR MANAGEMENT

1. SCUBA survey is essential to determine the presence of adult kokanee and redds at depths greater than 1.8 m (6 ft). However, towed divers cannot accurately estimate spawning area or spawners.

2. Lake Sutherland kokanee tend to spawn in groups that obliterate individual nests, which makes it impossible to estimate escapement from redd counts.

3. Canoe surveys along the lake shore can generate a total carcass count for the lake on a single day, which is suitable for determining spawn timing, nearshore spawning distribution, and year-to-year escapement trends.

4. Large numbers of adults are easily available for sampling via gillnetting. Mesh sizes of 5.1 to 8.9 cm (2-3.5 inches) are most effective. The net site 0.56 km (0.35 mi) west of the WDFW Boat Launch was the most productive.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS REGARDING SOCKEYE RESTORATION POTENTIAL

1. Verify the existence of lake bottom spawning concentrations on the north shore using divers towed from a boat or equipped with electric scooters to look for redds in mid-November of 1994.

2. After completing Item 1, collect adults by spawner survey and gillnetting from each minor spawning concentration and the major group at the Falls Creek area, and compare their spawn timing, size and age, and electrophoretic characteristics to determine if separate populations exist.

3. Estimate the lake's smolt-producing capacity by limnological measurements and modeling as proposed by WWFRO (1993a,b). This information will significantly improve assessment of sockeye restoration potential considering the technical difficulty in estimating spawner capacity.

4. Refine the minimum estimate of spawner capacity with an annual mid-November canoe survey to count carcasses along the shore.

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